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AFML-TR-77-152
PART II

DYNAMIC EVALUATION OF EXPERIMENTAL INTEGRAL FUEL-TANK SEALANTS

Research Applications Division
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

November 1978

Final Technical Report for period July 1977 - June 1978

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This final report was submitted by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio 45440, under Contract No. F33615-76-C-5253, Project Nos. 2421 and 7340, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433. William F. Anspach, AFML/MBT, was the Air Force Materials Laboratory Project Engineer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

William F. Anspach

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Project Engineer

FOR THE COMMANDER

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Nonmetallics Materials Division

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An exploratory development program has been performed to investigate and evaluate experimental integral fuel-tank sealant materials under laboratory conditions which closely simulate those of actual aircraft integral fuel tanks during flight. As part of this effort, a unique facility has been designed and fabricated for the evaluation of a variety of joint configurations. The facility consists primarily of a biaxial stress machine in which temperature, pressure, and vibrational strain can be programmed for automatic operation. Specimens can be strained longitudinally and torsionally to simulate actual flight conditions.

Block 20. Abstract (cont'd)

Frequency and amplitude of the strains can be independently set and recorded. Simulated fuel-tank and environmental pressure can also be adjusted independently. Early difficulties with sealant-failure detection and with undesirable thermal strains have been largely resolved and partial evaluation of continuous-fillet specimens utilizing one sealant material has been performed. A second evaluation apparatus is now under construction.

FOREWORD

This report was prepared by William R. Mallory of the Research Applications Division of Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton, Ohio 45440, under Contract F33615-76-C-5253. It was administered under the direction of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, with Mr. William F. Anspach (AFML/MBT) as Project Engineer.

The studies outlined in Part II of this report were conducted at Systems Research Laboratories, Inc. during the period July 1977 through June 1978. This work was a continuation of activities described in Part I, published in August 1977. Part I of the report covered the period February 1976 through June 1977.

The author would like to express appreciation to Mr. Lee E. Isom for valuable technical assistance. He also acknowledges the efforts of Mrs. Marian M. Whitaker of the Research Applications Division who made editorial comments on the report. Finally, the author would like to acknowledge the Air Force Project Engineer, Mr. William F. Anspach, for his many helpful discussions.

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INTRODUCTION

Optimization of modern aircraft has led to the widespread use of integral fuel tankage. This concept makes use of existing internal cavities in the wings and other parts of the aircraft for fuel storage, the aircraft structure becoming the walls of the fuel tank. These cavities are rendered fuel tight by sealing potential leak paths such as seams, joints, and fasteners with elastomeric sealants. Different sealant configurations such as fillet, faying surface, and channel (groove injection) have been developed for this purpose. Also new sealant materials are continually being developed both to solve problems on existing aircraft and to meet the requirements of new high-performance aircraft, including long-life performance in the fuel-tank environment at temperatures ranging from -65°F to +600°F. Evaluation of sealant materials should include their exposure to the complex set of physical variables which occur in actual use since failure can result from interactions and synergistic effects of the various physical properties, e.g., adhesion, strength, and elongation, over the entire temperature range. This is particularly important since sealant materials frequently operate near their physical limits.

Evaluation of new sealant materials and sealing configurations can be enhanced through the use of bench-scale dynamic apparatus. Since real-time dynamic testing of full-scale parts is very expensive, preliminary screening by dynamic laboratory evaluation under conditions closely simulating those found in actual aircraft is very desirable. Also, experimental sealants may be available only in limited quantities; therefore, bench-scale evaluations are desirable because only a relatively small amount of sealant material is needed. The evaluation apparatus must be flexible to allow for a variety of sealed joint configurations and environmental conditions.

Equipment developed under previous Air Force contracts (F33615-70-C-1422 and F33615-72-C-1594) demonstrated the feasibility of dynamic evaluations and clearly showed the need for the development of a more sophisticated evaluation system which would allow better control of evaluation parameters.

The objectives of the work described in this report were to develop suitable apparatus for dynamically evaluating fuel-tank sealants under simulated flight conditions, to design suitable test specimens in continuous-fillet, corner, and channel (groove-injection) configurations, and to evaluate sealant samples supplied by the Air Force Materials Laboratory using the apparatus developed and using evaluation parameters (temperatures, strain amplitudes, etc.) determined by AFML.

Under the present contract (F33615-76-C-5253), a system has been developed which is capable of simulating a complete flight including loading, take-off, cruise and high-speed flight, landing, and shutdown. The system is capable of repeating this flight simulation to a high degree of accuracy and of terminating the evaluation when the sealant leaks at a preset level. A second, improved system similar to the first is under construction. Suitable test specimens have been designed and, in the case of the continuous fillet, constructed.

The effects of thermal distortions of the specimen disc, which were discovered in the early stages of the program, have been minimized, and a satisfactory detector has been found for sensing leakage of fuel through the sealant upon failure. A continuous-fillet specimen utilizing 3M Company's polyester EC 2288 has been partially evaluated. A paper resulting from this program has been prepared for presentation at the 1978 SAMPE Conference.

SECTION II

DEVELOPMENT OF DYNAMIC EVALUATION EQUIPMENT

PHASE 1: FIRST SEALANT EVALUATOR

The design and construction of the first sealant evaluation machine was reported in AFML-TR-77-152, dated August 1977. At the time of that report, two problems were outstanding--detection of leaking fuel through a broken elastomer sealant specimen and thermal distortion of the disc, placing undesirable strains on the seal. Since that report, an appropriate leak-detection device has been incorporated into the system, and solutions have been developed which minimize undesirable thermal-strain problems. Evaluations have been conducted over extended periods of time without the mechanical tearing of the seals which was occurring at the time of the last annual report.

The evaluation apparatus in its present configuration is shown in Figs. 1-5. Figure 1 is a photograph of the system showing the evaluation chamber with associated equipment and the control console. Figures 2-4 are assembly drawings of the chamber, and Fig. 5 is a block diagram of the electrical, gas, vacuum, and cooling connections. Figure 6 shows a test specimen for a continuous fillet. This specimen consists of a cup and a disc with a central recession, the cup and the disc being joined by sealant material around the bottom of the cup. The system applies independent torsional and joint-opening forces to the elastomer joint. The disc represents the skin of the tank, and the cup represents the interior support structure to which the skin is bonded. The disc separates the upper chamber (which simulates the interior of the fuel tank) of the test machine from the lower chamber (which simulates the outside atmosphere). The exterior skin is subjected to temperature and pressure changes which are comparable to those encountered during normal flight and landing. The fuel tank must be full prior to the simulated flight and empty or nearly empty at the time of landing, with the pressure within the tank simulating that in a real aircraft.

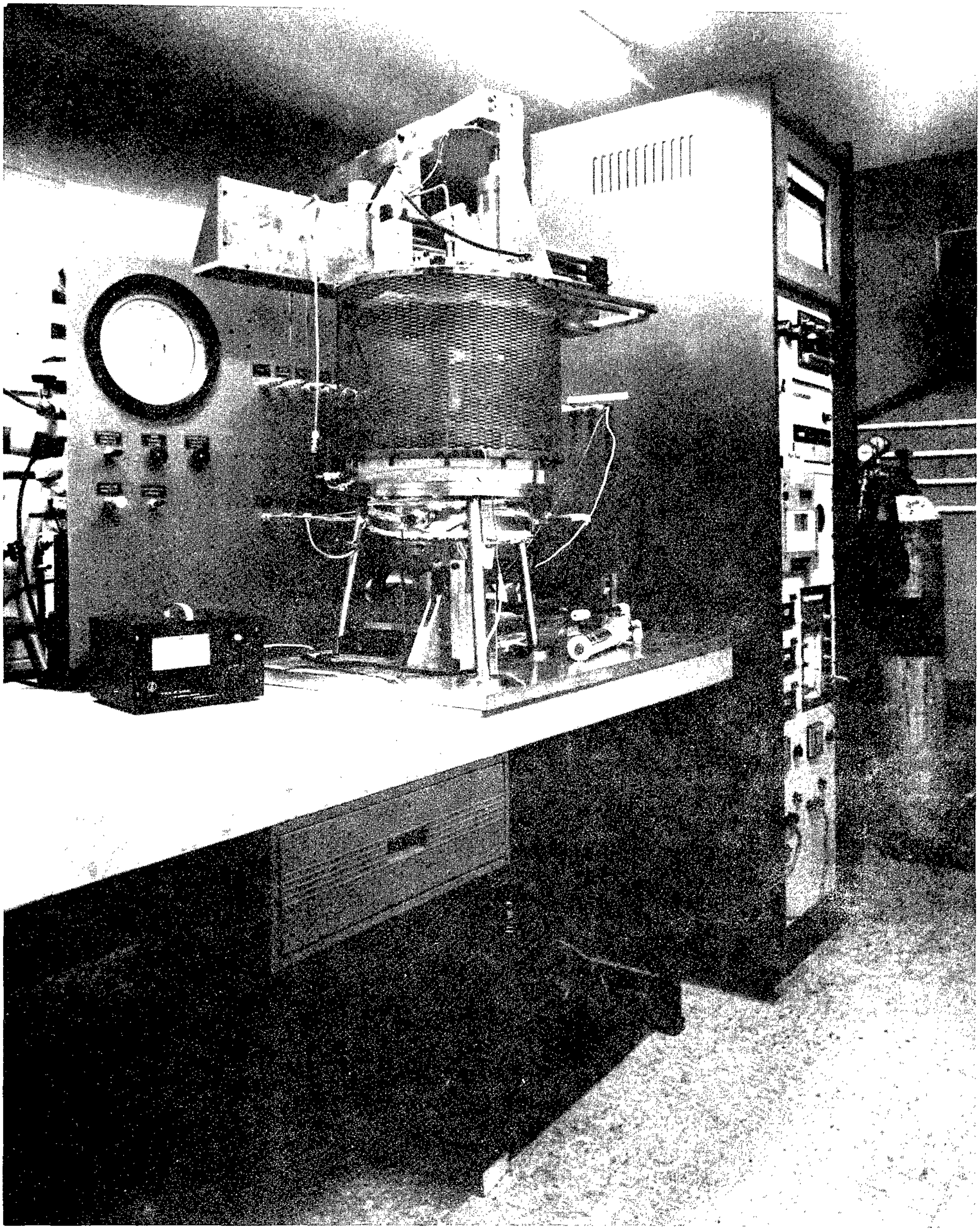


Figure 1. Dynamic Elastomeric Sealant Evaluator

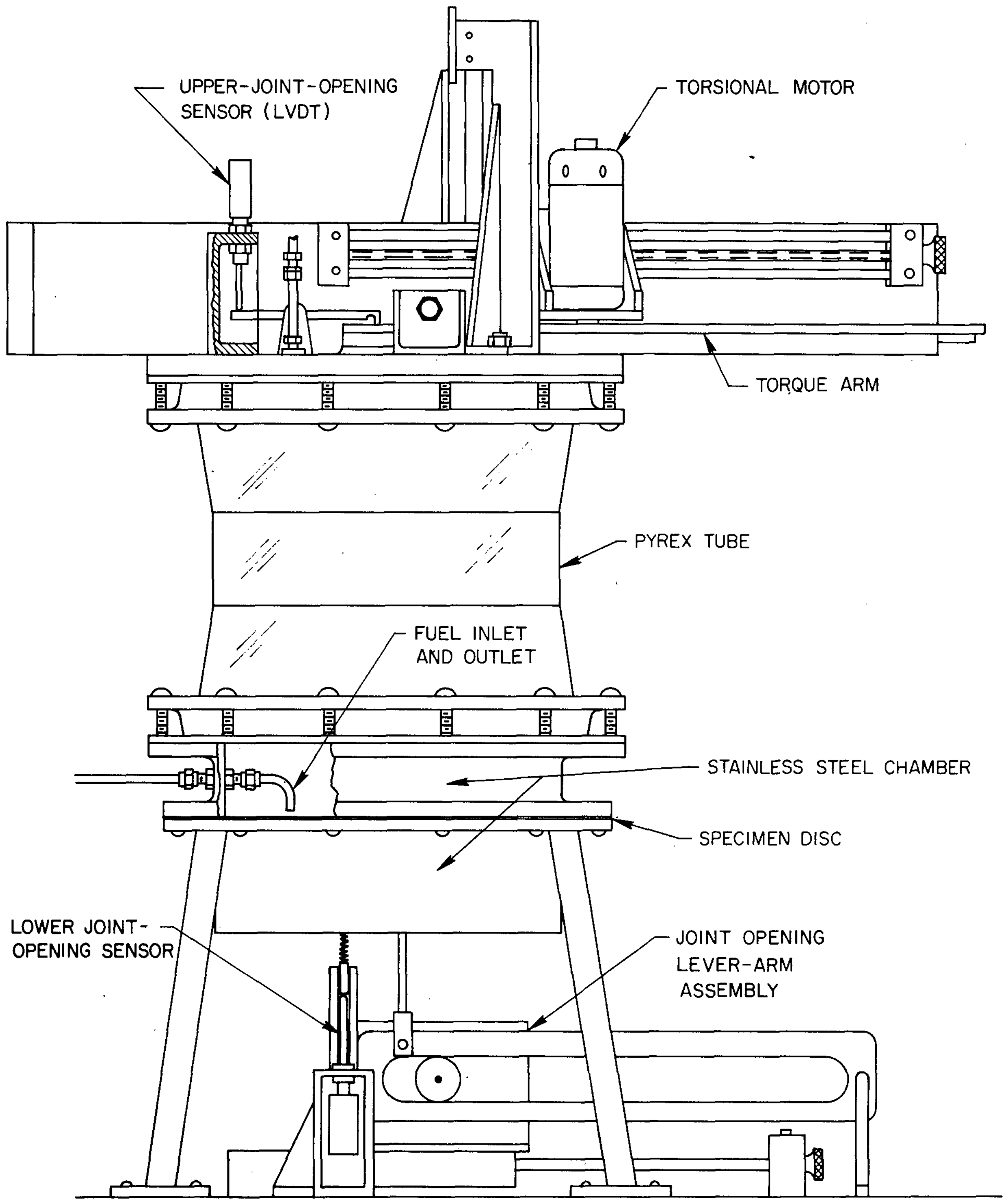


Figure 2. Front View of Evaluator

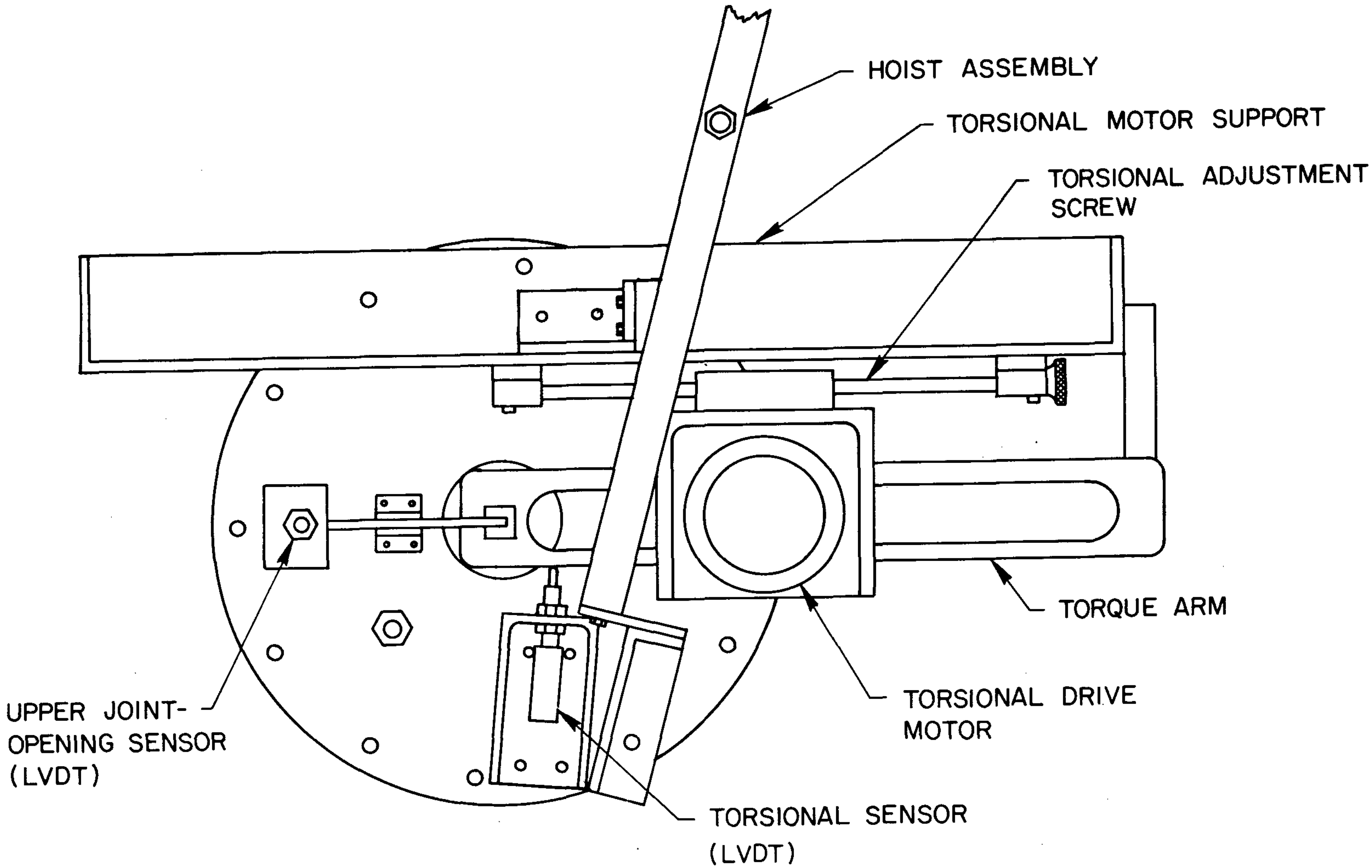


Figure 3. Top View of Evaluator

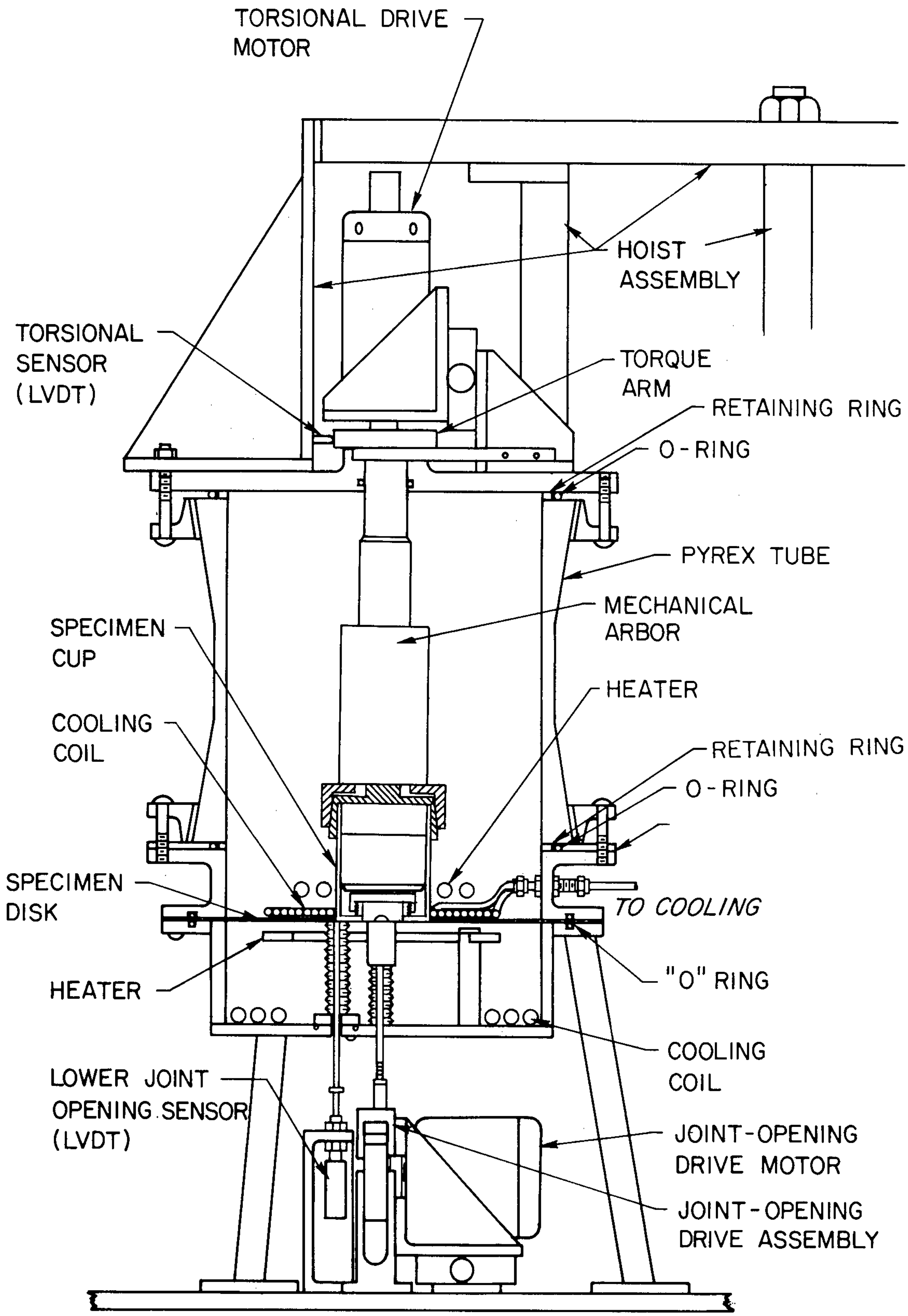


Figure 4. Side Section of Evaluator

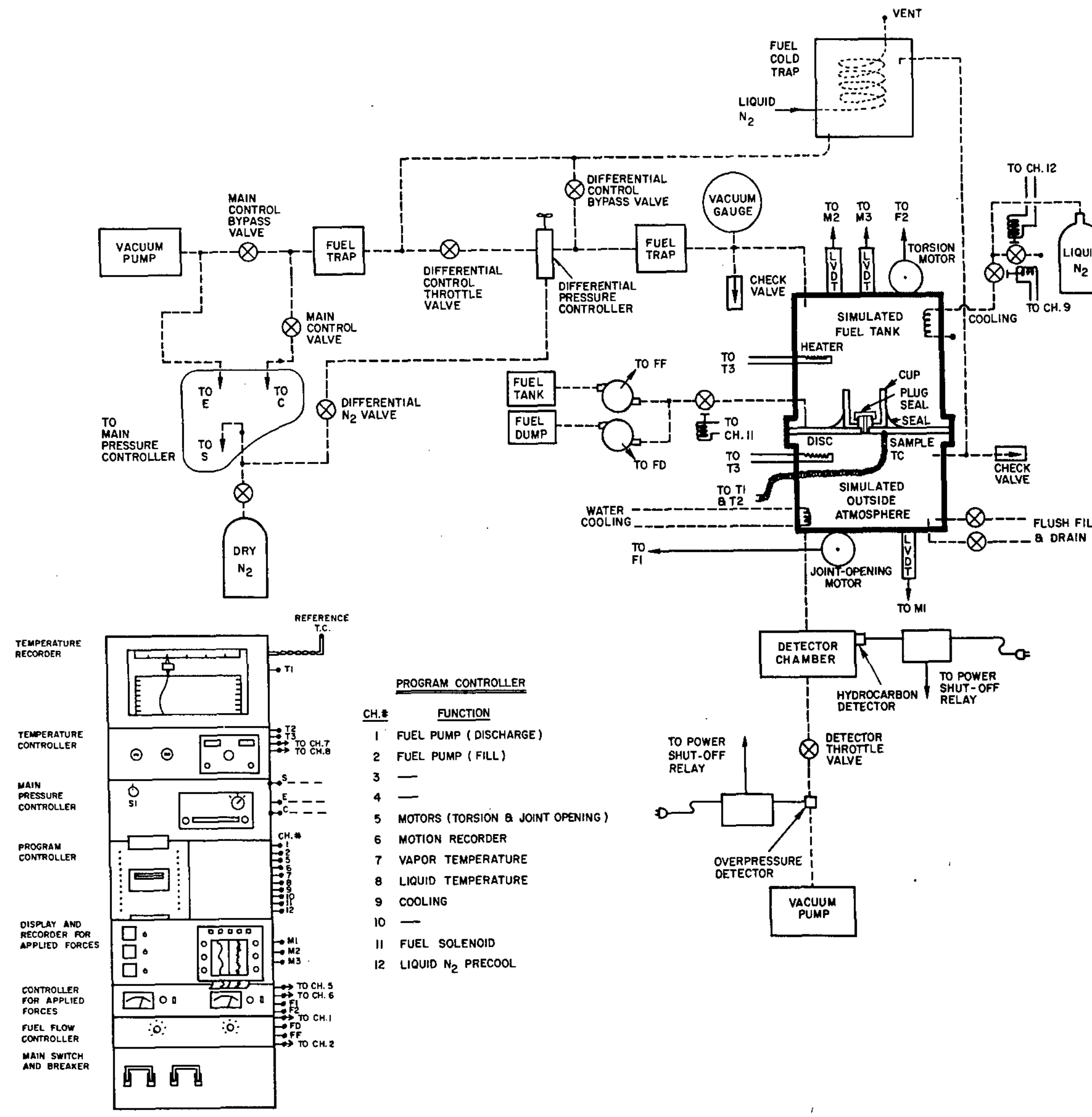


Figure 5. Block Diagram of Evaluator

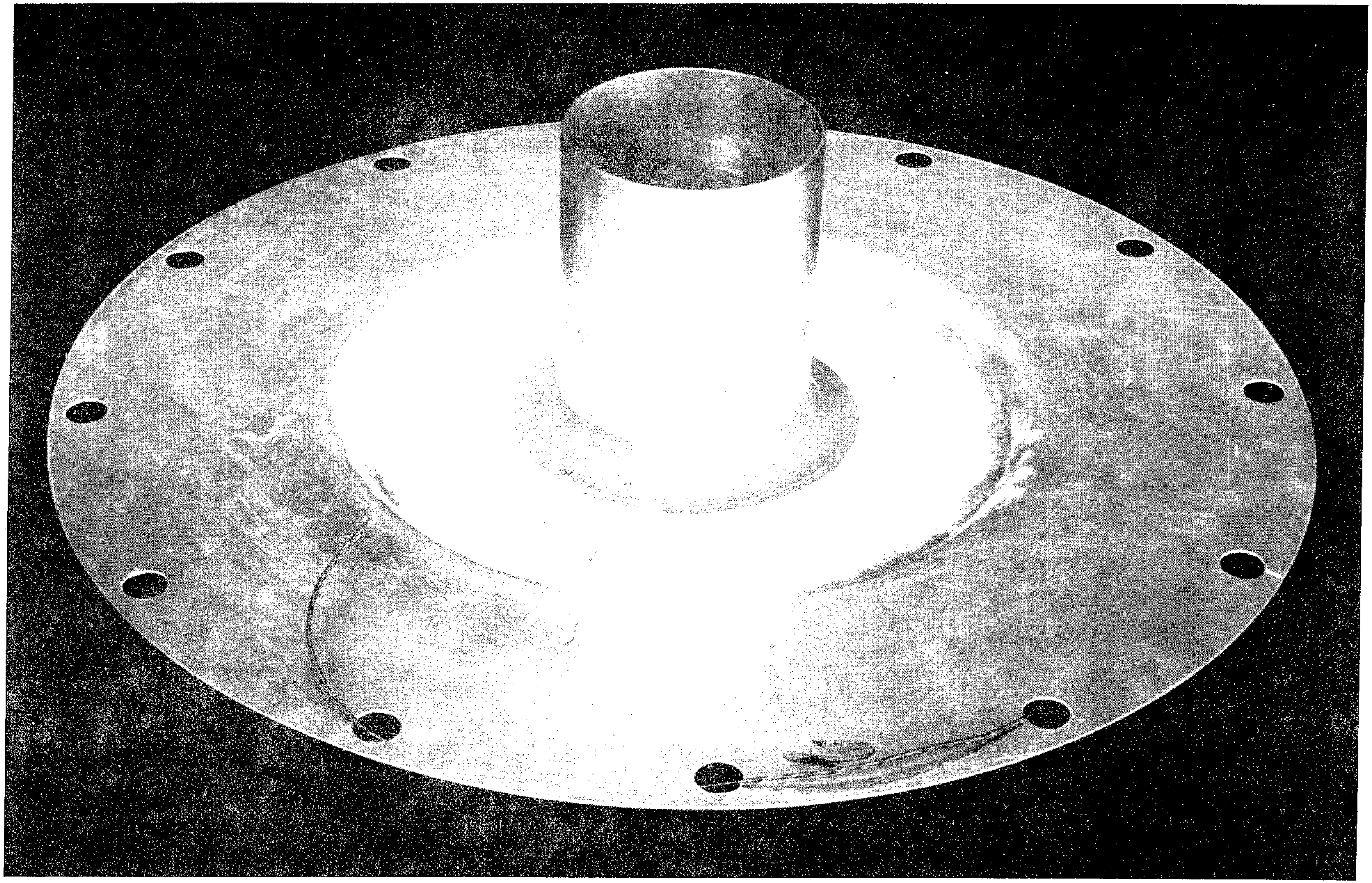


Figure 6. Continuous-Fillet Evaluation Specimen - Recessed Disc

For more details on the operation of the evaluator, see AFML-TR-77-152. The remainder of this section will deal with improvements made to the equipment since August of 1977.

The disc with the recessed center shown in Fig. 6 was developed to reduce the strains due to thermal distortion. Figure 7 shows a change (decrease) in height of several points on a flat disc when it is fastened in a horizontal position and heated as it would be during an evaluation cycle. Figure 8 shows the reduced thermal distortion which occurred during similar treatment of a recessed disc such as that shown in Fig. 6. The degree of improvement is evident. Presently evaluations are being conducted with a recessed aluminum disc formed by spinning. Attempts to spin such discs from cold titanium were unsuccessful. Quotes have been obtained for hot spinning. Also the Fabrication Shop in Bldg. 5 at Wright-Patterson Air Force Base has been hot pressing the recessed titanium discs. One disc has been completed and others are being made at present.

Improving the uniformity of disc heating also reduced the thermal-distortion problems. A copper heat-distributing disc was placed between the heater and the specimen disc, and the spacing between the heater and the specimen disc was increased.

Improved alignment of the apparatus components and modified specimen installation and operating procedures have also reduced extraneous mechanical strains on the test specimens. A counterbalance added to the hoist assembly, combined with stronger bracing of the assembly, improved the alignment between the upper and lower chambers and, hence, reduced the strains placed upon the sealant specimen during assembly. It was also learned that clamping the disc to the joint-opening drive during heating of the lower chamber reduced the effects of the thermal distortion. Pulling the disc downward and clamping it without heating has the same beneficial effect. It is also necessary to evacuate and fill the dual chambers slowly to avoid large transient pressure differentials due to differences in volume and pump/fill rates. A number of seals were torn before this problem was recognized.

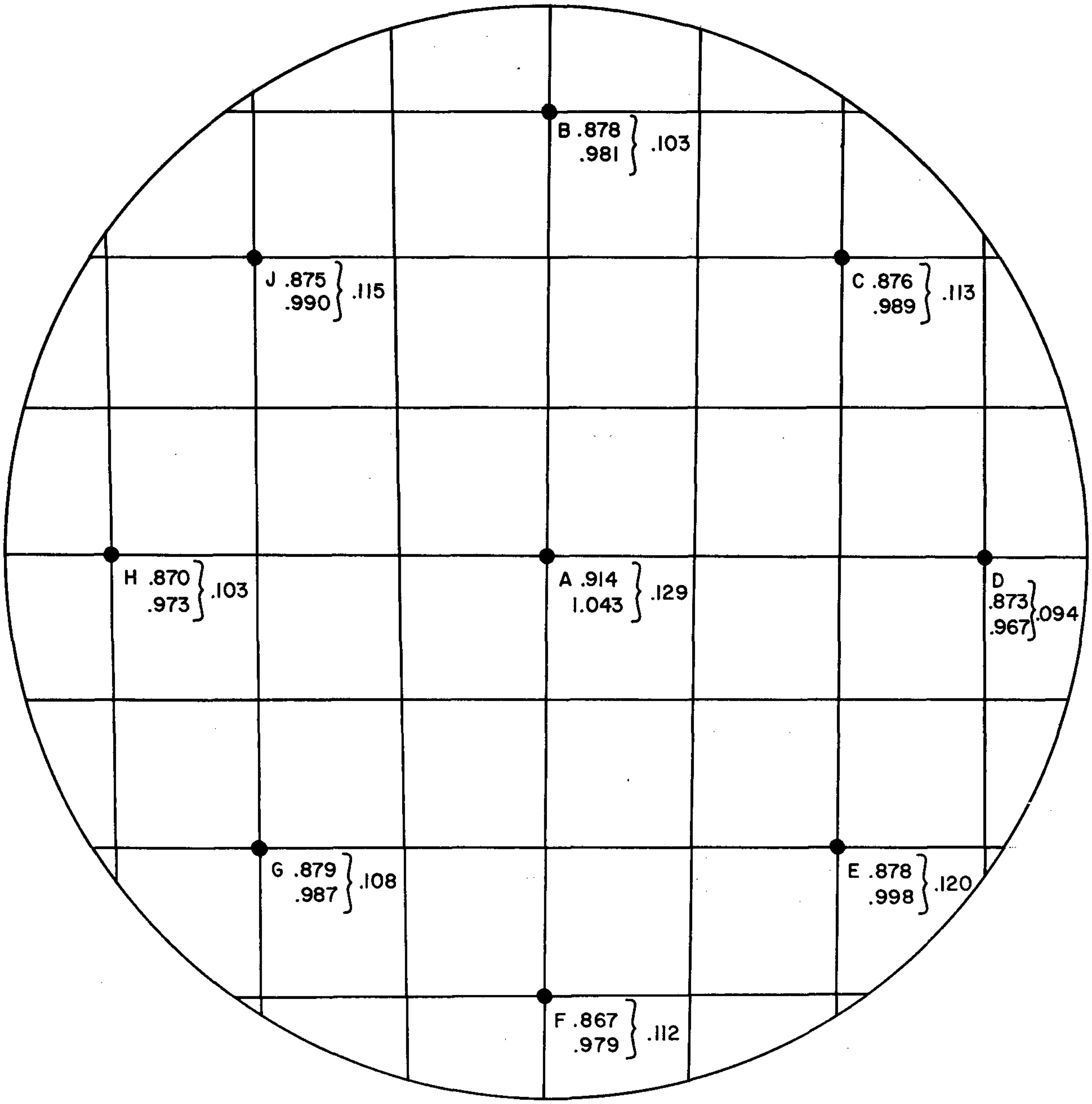


Figure 7. Thermal Distortion of Central Portion of Flat Disc. Numbers indicate heights of the points (A, B, etc.) above an arbitrary reference level, the upper number of each set corresponding to room temperature and the lower one to 550°F.

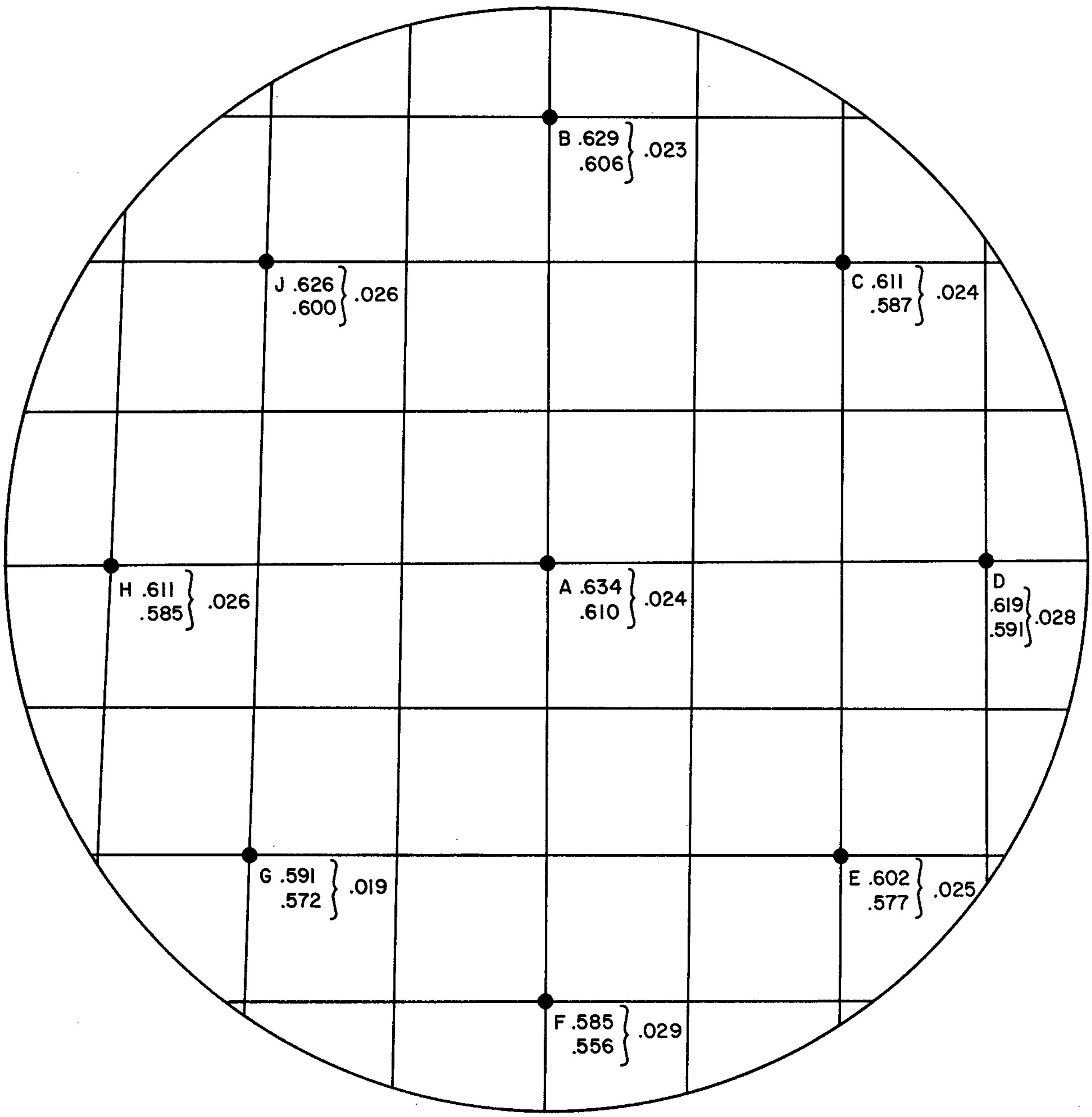


Figure 8. Thermal Distortion of a Recessed Disc (see caption of Fig. 7 for explanation)

Before the Government-furnished leak-detection equipment arrived, it became evident that the thermocouple gauge being used at that time was inadequate for detecting fuel leakage after specimen failure. The gauge primarily senses pressure changes, and a slow leak does not produce sufficient pressure change to be registered reliably. After considerable searching, a detector manufactured by International Sensor Technology (IST), similar to one which was being used by the Air Force Weapons Laboratory in Albuquerque for sensing fuel vapors, was purchased and installed in the machine. Experimentation showed the detector to be very sensitive. It was necessary to build a separate chamber for the detector sensor where the sampling flow rate from the lower chamber and the amount of dilution of the sample by clean air at the sensor could be controlled separately. Figure 9 is a schematic diagram of the detector chamber. The sensor utilizes oxides whose resistivity varies with exposure to various substances. When the fuel vapors are removed, the detector reading returns to its original value. The sensor currently being used was installed several months ago, and no deterioration in sensitivity has occurred.

Due to the sensitivity of the detector, it is necessary to clean the lower chamber thoroughly after any appreciable leakage following specimen failure. Adequate procedures for this have been developed. Furthermore, small amounts of vapor were found to diffuse through the differential pressure-control unit from the upper chamber. A cold trap which utilizes liquid nitrogen has been constructed and installed in this line to trap fuel vapors. The leak detector is currently functioning effectively.

After reducing the effects of thermal and undesirable mechanical strains, evaluations of a test specimen were conducted utilizing 3M Polyester Sealant, EC 2288, at a vapor temperature of 550°F. After the evaluation had continued for 32 cycles without failure, it became a matter of concern that such a long time was required to break the specimen at that temperature. The evaluation was discontinued, and extensive temperature checks were conducted. It was determined that the temperature of the sealant material was not the same as that of the controlling thermocouple because of poor thermal contact between

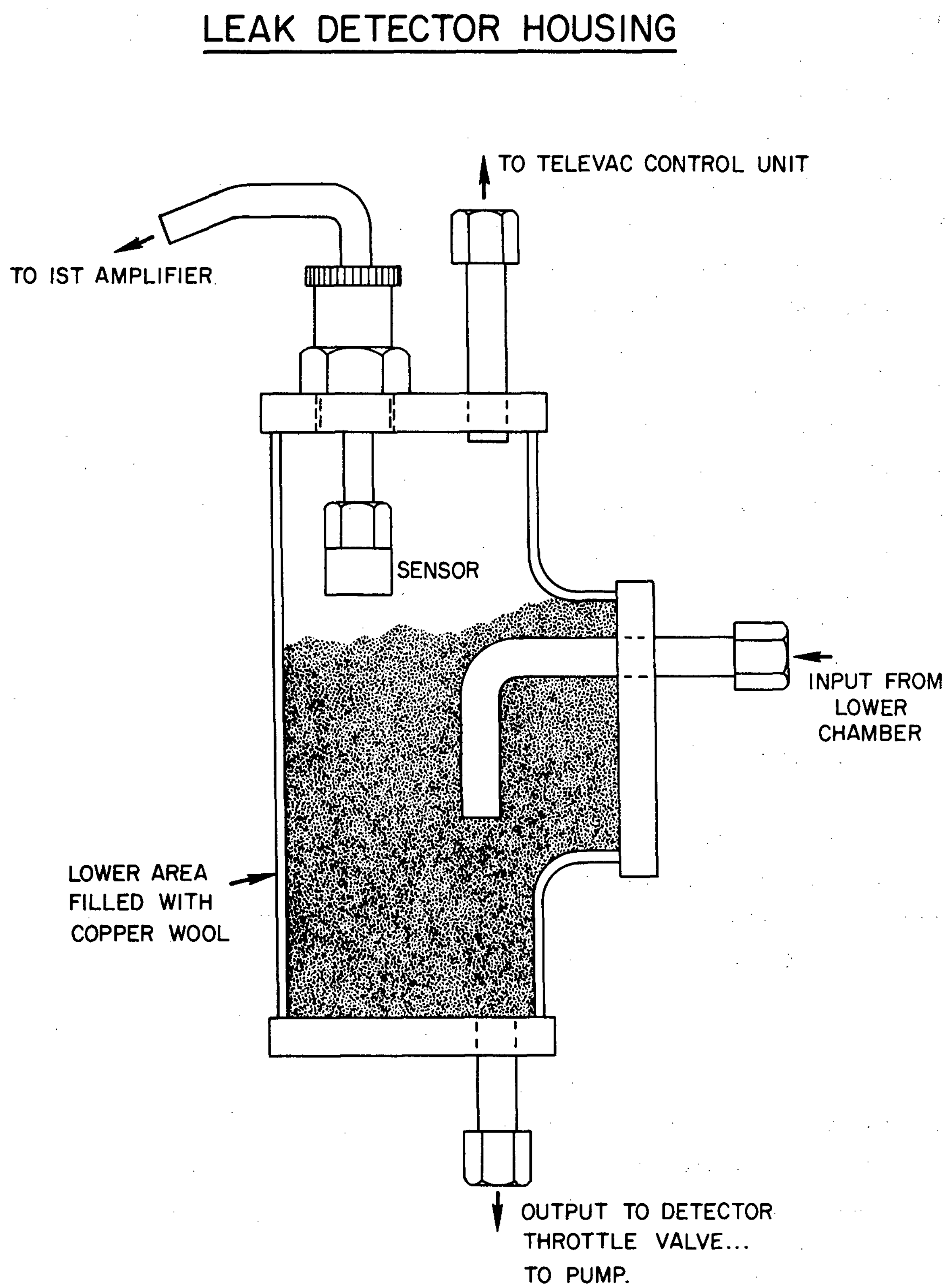
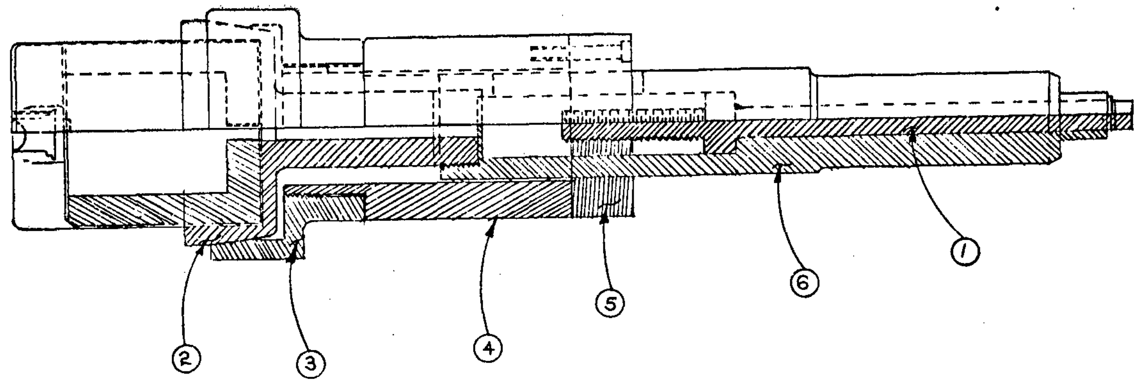


Figure 9. Leak Detector Housing

the specimen disc and the specimen cup and also between the control thermocouple and the specimen disc. An additional heater was placed in the upper chamber and the thermocouples were welded to the disc rather than being held by spring contact. These two steps solved the temperature problem, but the additional heating in the upper chamber created other difficulties.

At the higher temperature generated in the upper chamber with the additional heater installed, the hydraulic arbor becomes hotter. Since liquids expand about one order of magnitude more than solids, the differential expansion in the arbor between the steel parts and the hydraulic oil caused high pressures to build up inside and the arbor seals to break. Unsuccessful attempts were made to locate low-expansion oil or grease and, simultaneously, improved backup rings were added to the seals. However, the pressures were too great, and the seals broke. Estimates of the pressure inside the arbor before breakage were 15,000 to 30,000 psi.

A procedure utilizing the arbor core without oil and an adjustable backup ring allowed continuation of evaluations at a slower pace. Meanwhile, a mechanical arbor was designed and built to replace the hydraulic one. Figure 10 shows a cross section of this arbor. Like the hydraulic arbor it replaces, the mechanical arbor is adjusted from the top to grip the cup. The gripping mechanism is a machined chuck which holds the cup from the outside. Before lowering the upper chamber and tightening the arbor, an adjustable collet is placed inside the cup and tightened against the cup wall. Thus, as is the case with the hydraulic arbor, the cup is gripped from both inside and outside in order that differential thermal expansion of the cup and arbor during the temperature cycling will not loosen the cup and allow slippage. This arbor was installed recently, and indications are that it performs satisfactorily. The mechanical arbor has expansion capabilities of at least 0.020 in., considerably more than those of the hydraulic arbor. No problems should be encountered with cups sticking to the new arbor, as was the case with the hydraulic arbor. Tolerances on the specimen cups are also now much less critical.



CROSS SECTION ASSEMBLY

NO	PARTS LIST
1	ADJUSTMENT ROD
2	STEP CHUCK
3	STEP CHUCK CLOSER
4	HOUSING
5	PRESSURE BLOCK
6	ADJUSTMENT HOUSING

SPEC/MFR NAME	-4	-3	-2	-1	QTY	PART NO.	CODE IDENT	DESCRIPTION	ITEM NO.

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.

TOLERANCES:

.xx =
.xxx =
.xxxx = BASIC

ANGLES = ± 30'
FRACTIONS = ± 1/32

ALL SURFACES: ✓

MATERIAL AS NOTED

FINISH AS NOTED

	SIGNATURE	DATE
APPROVED		
CHECKED		
DRAWN	D. Jackson	5/17/78

CONTRACT NO. 6901-01-12

SRL PROJECT APPROVAL

GOVT ACTIVITY APPROVAL

NEXT ASSY | USED ON

APPLICATION

SYSTEMS RESEARCH LABORATORIES, INC.
2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440

ARBOR

SIZE	CODE IDENT NO.	DRAWING NO.
C	14590	00/00

SCALE NONE   SHEET 4 OF 4

Figure 10. Mechanical Arbor

The second change necessary to accommodate the upper heater was modification of the seals at the top and bottom of the Pyrex section. Higher temperatures made it necessary to replace the Buna-N gaskets with Viton. Because of the high cost of Viton, a stainless steel backup ring was tack welded to the stainless steel base and lid and standard Viton O-rings were then used instead of the flat gasket. With this arrangement, better vacuum can be achieved during initial pump-down which implies that leakage has been reduced and, consequently, there is less risk of fire.

An additional improvement which has been made in the apparatus is better control of the differential pressure. The Hoke 2403 Differential Regulator used early in the program proved inadequate because of leakage. It was replaced by a Wallace-Tiernan Aneroid Manostat (see Figs. 5 and 11).

Development of a method for sealing inside the cup was also determined to be necessary since the cup-arbor contact provided an imperfect vacuum seal. Leakage between arbor and cup not only made it impossible to maintain a pressure differential between the top and bottom chambers but allowed fuel vapors to leak past the elastomeric sealant and trigger the leak detector. Initially a plug was made for the cup which incorporated an O-ring which sealed against the cup wall. This arrangement was satisfactory until the upper heater was added; then the cup became too hot for the O-ring material (even for Viton).

Recently the cups have been sealed using a standard plumbing fitting, welded into the bottom of the cup. This procedure has been used successfully with stainless steel cups. An effective method of sealing the titanium cups is being sought. Attempts to weld a stainless steel fitting in them were unsuccessful (the weld breaks while cooling). Presently, attempts are being made to braze or silver solder the parts together. It is possible (although expensive) to buy titanium plumbing fittings which can probably be welded into the titanium cups if attempts to braze the stainless steel fittings fail.

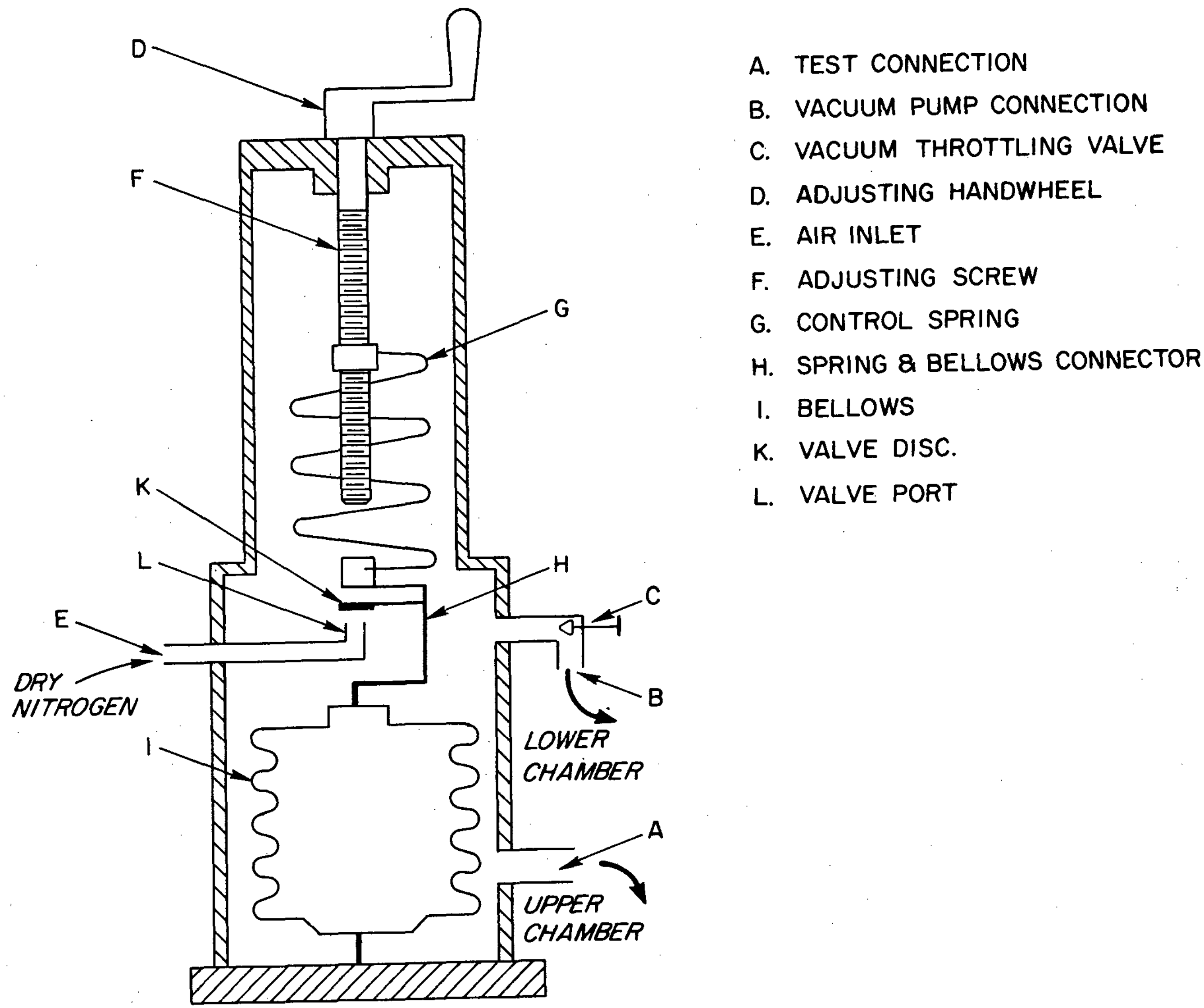


Figure 11. Schematic Operation Drawing of the Aneroid Manostat

As part of the improved pressure control, the cooling coil above the specimen disc for jetting cold nitrogen vapor from evaporated liquid nitrogen onto the disc was replaced by a closed, tightly wound coil through which nitrogen vapor and liquid nitrogen are circulated. This reduces the load on the vacuum pump during the cooling cycle. A separate vacuum gauge was added to the upper chamber to allow monitoring of the pressure (the Mensor controller automatically indicated the pressure in the lower chamber).

Additional improvements made since the last annual report include:

1. Improved fuel traps to reduce the amount of fuel vapors reaching the pressure-control units and the vacuum pumps. These traps are also sealed for vacuum more adequately than the earlier ones.
2. Problems with shorting of the heater to the shell were solved by sealing the heater ends in order to prevent fuel from leaking into the magnesium oxide insulation which separates the shell from the heater wire.
3. Titanium cups have been spun and pressing techniques developed for forming recessed titanium discs. As soon as a method of sealing the titanium cup is developed, evaluations can be conducted using all-titanium specimens.
4. A slight interaction between the measurements of joint-operating motion and torsional motion caused by the loose fit of the O-ring seal around the arbor at the point where it exits the chamber has been reduced to a negligible level by the addition of a metal collar around the arbor at the exit.

PHASE 2: SECOND EVALUATION UNIT

Improvements which were made to the first evaluation machine are being incorporated into the second. In addition, some features--which were difficult and/or expensive to include on the first machine because their desirability became evident only after the apparatus was constructed--are being built into the second machine.

The Pyrex chamber of the first machine provides somewhat less visibility than desired because the optical quality of the Pyrex is poor and also because it is desirable--for safety reasons--to place a punctured metal screen around it. Therefore, the second machine was designed with a stainless steel chamber, which has three viewing ports placed at appropriate points. These ports will allow viewing of any point in the chamber and will allow access to the chamber with the specimen in place--a feature lacking in the first machine.

In the second machine, torsion on the cup is measured by placing an LVDT push rod against a tab clamped directly onto the cup. This is a more direct method than measurement of arbor motion which is presently being utilized. This new method should reduce the possibility of error due to slippage, although no such slippage has been observed.

Adjustment of strains is accomplished by means of a machine boring head used as a continuousl-y adjustable cam. This reduces the bulkiness of the strain drive assembly which is particularly desirable in the case of the torsional drive. The torsion motor on the first machine must be moved a considerable distance off the chamber axis to apply the required range of torsional strains. This causes alignment difficulties.

Since the Wallace-Tiernan Aneroid Manostat functioned so well as a differential controller in the first machine, two Manostats are being used in the second machine--one for the control of pressure in the lower chamber and one for the differential controller for the upper chamber.

The Mensor quartz manometer controller presently in use on the first machine as a lower-chamber pressure controller and a Manostat will be connected in such a way that either can be used with either machine (making the Mensor available for vacuum diagnostics). The reason for replacing the Mensor with the Manostat is that the Mensor is much more expensive than the Manostat.

In the second machine a smaller bellows is used in the measurement of disc deflection. This will reduce the force placed on the disc by the differential between the pressure in the lower chamber (3-5 psi) and ambient pressure (14.7 psi). (The inside of the bellows is open to atmospheric pressure.) This pressure differential creates an azimuthally asymmetric force on the disc and causes some uncertainty in deflection measurements. When the bellows in the first machine must be replaced, a smaller bellows will be used.

Cooling coils on the new machine will be silver-soldered directly to the chamber walls, making them more effective because of better thermal contact.

A strain recorder capable of slower speeds than the 1 mm/sec minimum on the first evaluator has been purchased. If the recorder on the first machine runs continuously, 120 ft of paper per hour is used (for that reason the recorder on the first machine has been programmed to run intermittently).

Design of the second machine was delayed until all major difficulties with the first machine had been resolved. It seemed unwise to design the same shortcomings into the second machine. Except for the modifications noted earlier in this section, the second evaluator is similar to the first. Drawings on the new machine have been completed, long-delivery parts have been ordered, and quotes are being obtained on machining of the chamber.

SECTION III

EVALUATIONS

An Elastomer Laboratory has been created by the Research Applications Division at SRL's Research Campus on Indian Ripple Road in Dayton, Ohio, expressly for the purpose of conducting elastomeric sealant evaluations. Fuel-storage and waste-fuel tanks are mounted in a protected external enclosure attached to the laboratory wall. All flexible tubing used in pumping the fuel as well as the fuel pumps themselves are housed in this enclosure. An automatic fire-protection system using ultraviolet flame detectors and Halon 1301--a personnel-safe fire suppressant--has been installed in the laboratory. This system has auxiliary battery power in case of power failure. It is monitored 24 hours a day by ADT Security Systems.

A test-specimen configuration for evaluation of continuous-fillet seals has been designed. The continuous-fillet cup and disc specimen was shown in Fig. 6. It is anticipated that the disc used for continuous-fillet evaluations will be used for most other cases. A preliminary design for corner-seal evaluations is shown in Fig. 12. The upper part of this cup will fit the arbor, and the lower part will simulate the corner configuration. The two parts will probably be constructed separately and then welded together. For titanium specimens the top part can be hot-spun if suitable titanium tubing is not available (it was not available at the time the cups for the continuous fillet were made). Aluminum samples will be made from sheet aluminum (bottom) and aluminum tubing (top) welded together. Figure 13 shows a preliminary design of a test specimen cup for use in channel sealant evaluations.

Evaluations are being conducted on several sealants selected by the AFML Project Engineer. The material chosen for evaluations for initial equipment checkout was Dow Corning 77-028 fluorosilicone sealant. Due to limited availability of this material and an extended check-out phase of the evaluator, the evaluations were switched to Dow Corning 77-108 (FCS 210)--a hybrid fluorosilicone/fluorocarbon--and then to a 3M Company polyester sealant,

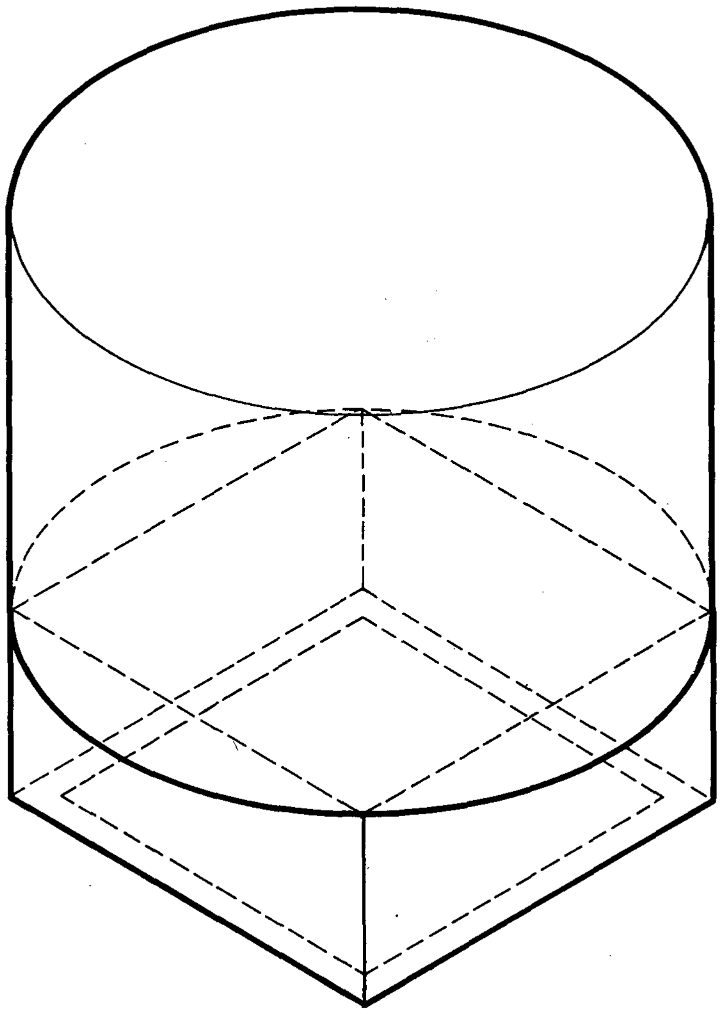


Figure 12. Corner-Seal Cup Specimen

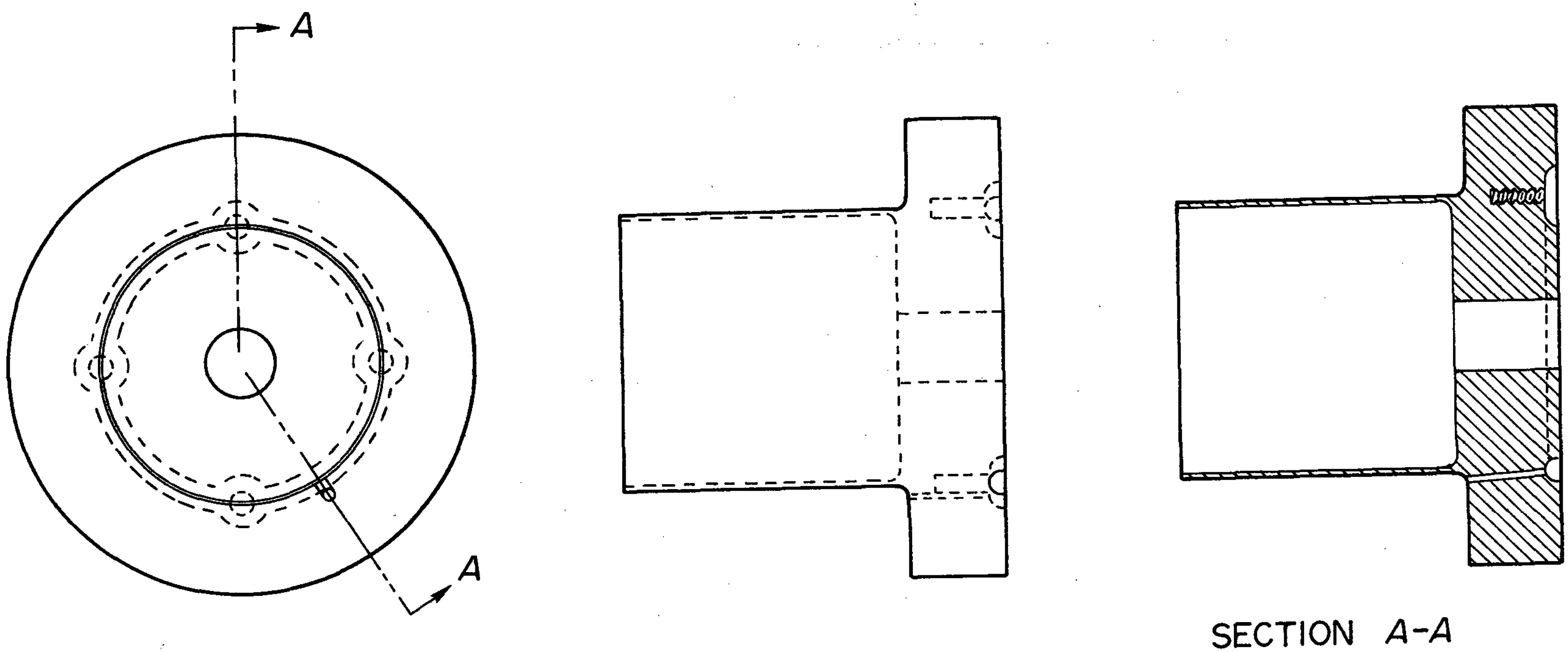


Figure 13. Channel-Seal Cup Specimen

EC 2288. The latter material has a shorter life at high temperatures than the FCS 210 and, hence, speeded up verification of evaluator performance at high temperatures. Also, data are available on this material from other sources so that a correlation with actual flight data can be made. The sealants are being evaluated under a variety of conditions (e.g., fuel vapor over the 450-550°F temperature range). Each data point represents evaluation of several samples of the same material under identical conditions. A complete evaluation of an elastomeric sealant will consist of several data points. The goal is to provide sufficient information to permit correlation with more expensive flight-test data in order that the more economical laboratory method may be used in evaluating presently available sealants and those now under development.

The test procedure for the initial evaluations, which was detailed in Technical Report AFML-TR-77-152, is reported here with certain modifications which have been made in the interim. First, the sealant to be evaluated is used to bond the specimen disc to the specimen cup (see Fig. 6). The upper chamber is then raised, the specimen inserted into the tester with Viton O-rings beneath and atop the disc, and the thermocouple which is welded to the disc is connected to the external lead. The disc is then fastened to the joint-opening drive stem and the cup bottom is sealed by screwing a plug onto the modified connector (essentially one-half of a tubing union) which has been welded or brazed to the cup. The expandable collet is then placed in the cup and tightened snugly against the inside. Lowering the top chamber onto the disc then completes the separate sealing of the upper and lower chambers. After the top chamber is lowered and fastened in place, the arbor is tightened by a drive extending through the chamber lid.

Prior to the evaluation, the upper and lower chambers are evacuated with the main-control valve and the differential-control bypass valves open and the dry nitrogen shut off. Then the bypass valves are closed and the nitrogen supply connected. The chambers then come to the preset pressures. For the duration of the evaluation, both chambers are filled with nitrogen. The pressure in the lower chamber, which simulates the region outside a fuel tank, is preset at a level (e.g., 1/3 atm) which simulates atmospheric pressure during an actual flight. The upper chamber--which corresponds to the interior of the fuel tank--is maintained by the differential regulator

at a pressure which is about 1 psi above that in the lower chamber and thus simulates a pressurized fuel tank.

At the beginning of the evaluation cycle, fuel (e.g., JP-7) is pumped into the upper chamber. Independently programmed tension and torsional deflections (e.g., 0.005 in. tension at 10 cycles/min. and 0.002 in. torsional at 2 cycles/min.) are then applied simultaneously to the specimen. For the remainder of the cycle, the strains are measured by LVDT's and recorded on a strip-chart recorder. Figure 14 shows a sample of these recorded strains. Simultaneously with the start of the deflections, the test specimen is heated to a temperature (e.g., 250°F) simulating that to which a tank containing liquid fuel might rise. Figure 15 shows a recording of a typical temperature cycle through which the elastomeric sealant goes during an evaluation. The temperature rise (A to B in the figure) is that referred to above.

This portion of the cycle is continued for a specified time (e.g., 30 min. to Point C in Fig. 15); then the fuel is pumped out--except for a thin layer on the bottom of the upper chamber--and the temperature is elevated (e.g., to 550°F to Point D in Fig. 15) to simulate flight with a largely vapor-filled tank. The higher vapor temperature is held for another preset period (e.g., 90 min. to Point E in Fig. 15). The application of mechanical strains continues during this time. Afterward, the specimen is cooled by a combination of vapor from liquid nitrogen [solenoid valves (see Fig. 5) are opened during the cooling phase] and water to simulate the cooling which occurs during subsonic flight and landing. Mechanical strains are also applied during the cooling cycle.

If the sealed joint has not failed, the cycle is then repeated automatically for up to 24 hr. If, after 24 hr, the sample still has not failed, the program card is reset manually and the evaluation then continues automatically. When the sealant fails, leakage of the fuel into the lower chamber is detected by an IST hydrocarbon detector as discussed in Section II. After a leak has been detected, a check is made by closing off both the upper and lower chambers from the control units and observing the upper-chamber vacuum gauge to determine whether the pressure in the upper chamber

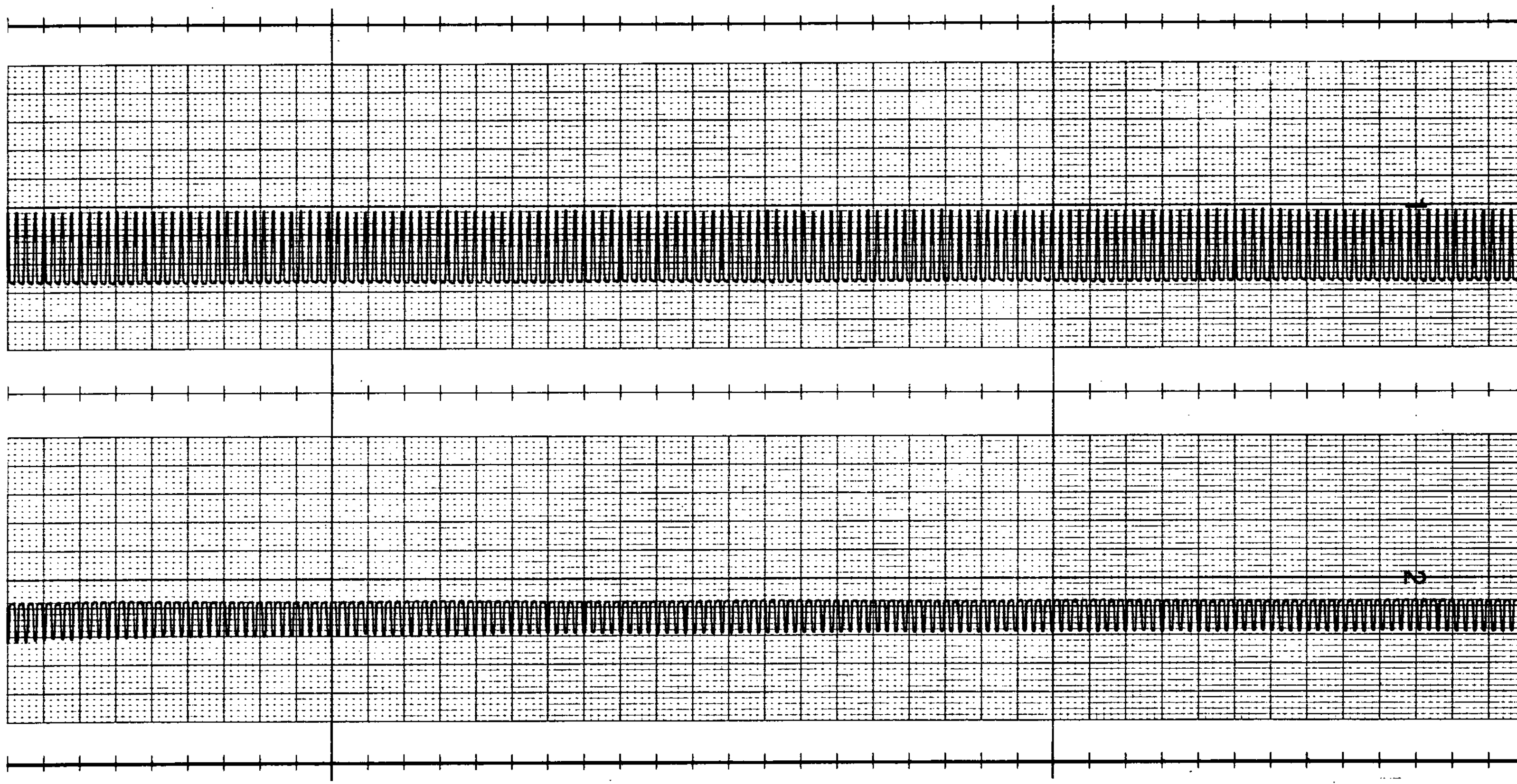


Figure 14. Joint-Opening (bottom) and Torsional Motion (top) for a Sealant Evaluation
Time Scale: 1 sec/mm; Motion Scale: 1 mil/mm

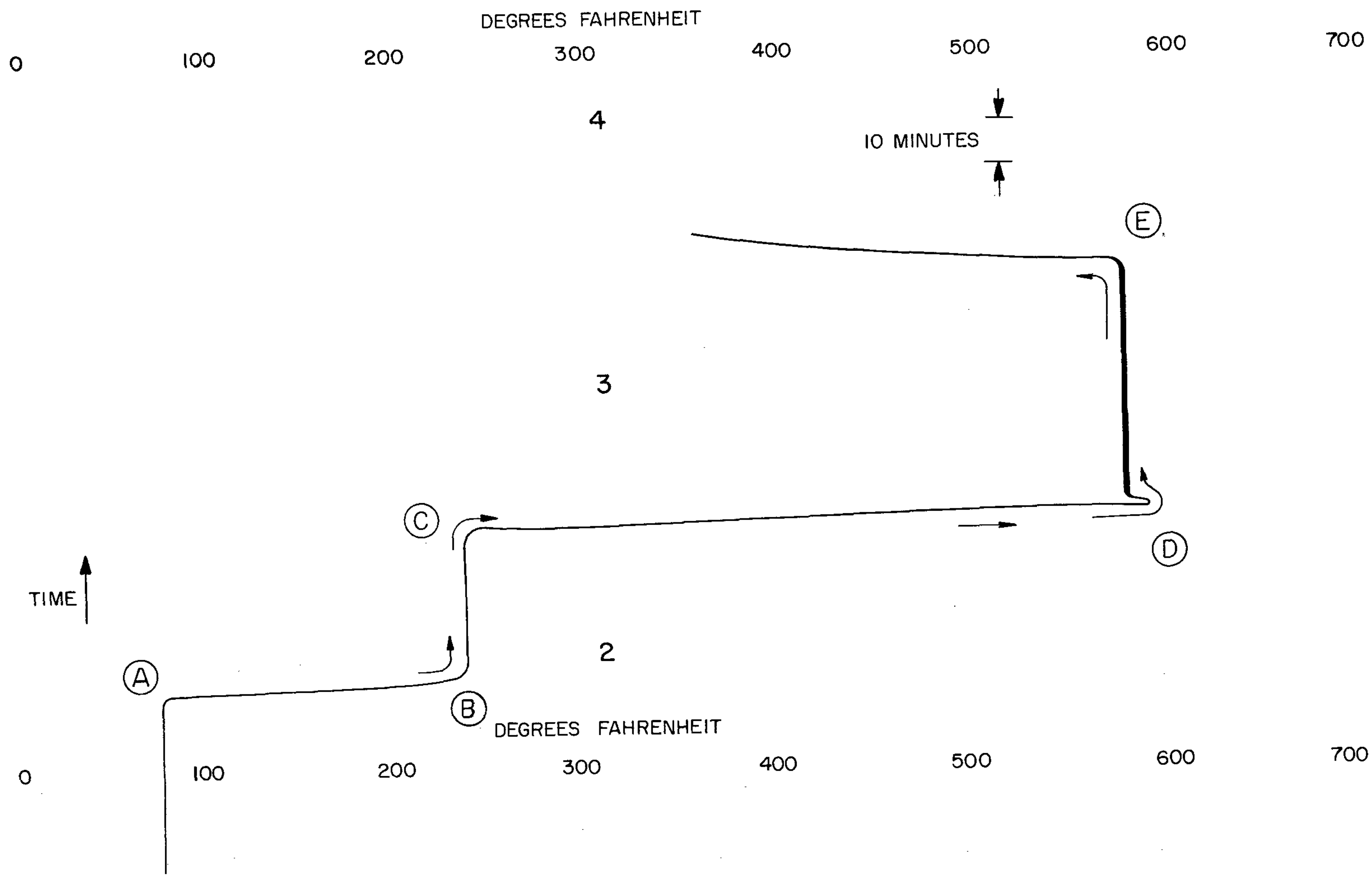


Figure 15. Thermal Cycle for a Sealant Evaluation

decreases toward that in the lower chamber. If there is still some question concerning sealant failure, a second check is made which consists of placing water on top of the disc, pressurizing the bottom chamber, looking for bubbles in the water above the elastomer.

SECTION IV

RESULTS

Figure 16 gives results to date on evaluation of continuous-fillet specimens of 3M Company Polyester EC 2278. Two specimens have been tested at a vapor temperature of 550°F and two at 485°F. (A third specimen evaluated at 485°F showed a leak on the third cycle, as reported in the 15 May 1978 Monthly Status Report. It is now believed that this was a false indication due to leakage of fuel vapors through the differential control path.) A fifth specimen was tested at 500°F. The liquid temperature was held constant at 250°F, and strain amplitudes were held constant at ±5 mils for the torsional and 5 mils for the joint-opening strains. The liquid temperature phase was 30 min. and the vapor phase 90 min. The cycle given in the graph is the one in which the failure occurred. An additional check failed to verify the leaks at 485°F. Therefore, these are marked minimum. It is possible that the leaks were real and that they "resealed" at room temperature. However, shortly after these tests, it was learned that over long periods of time, vapor from the top chamber leaked into the lower chamber--probably through the differential control unit. This leakage may have triggered the leak detector and terminated the tests.

Only preliminary results on the Dow Corning materials 77-028 and 77-108 (FCS 710) are available at this time. When these materials were being evaluated, difficulties were encountered with thermal distortion of the disc. Also adhesion of 77-028 was a problem early in the program, but this problem has since been solved. The roles of thermal distortions and poor adhesion in these failures are not clear.

After the discovery that thermal distortions were placing additional undesirable strains on the elastomer sealant, an investigation was undertaken to determine the nature of the problem and to solve it. After a method was developed for measuring the strain generated by thermal effects (see Figs. 7 and 8), the effects of various contributing factors, including heat distribution, heater spacing, and the shape of the disc, were examined. As a result of this investigation, the recessed disc shown in Fig. 6 was

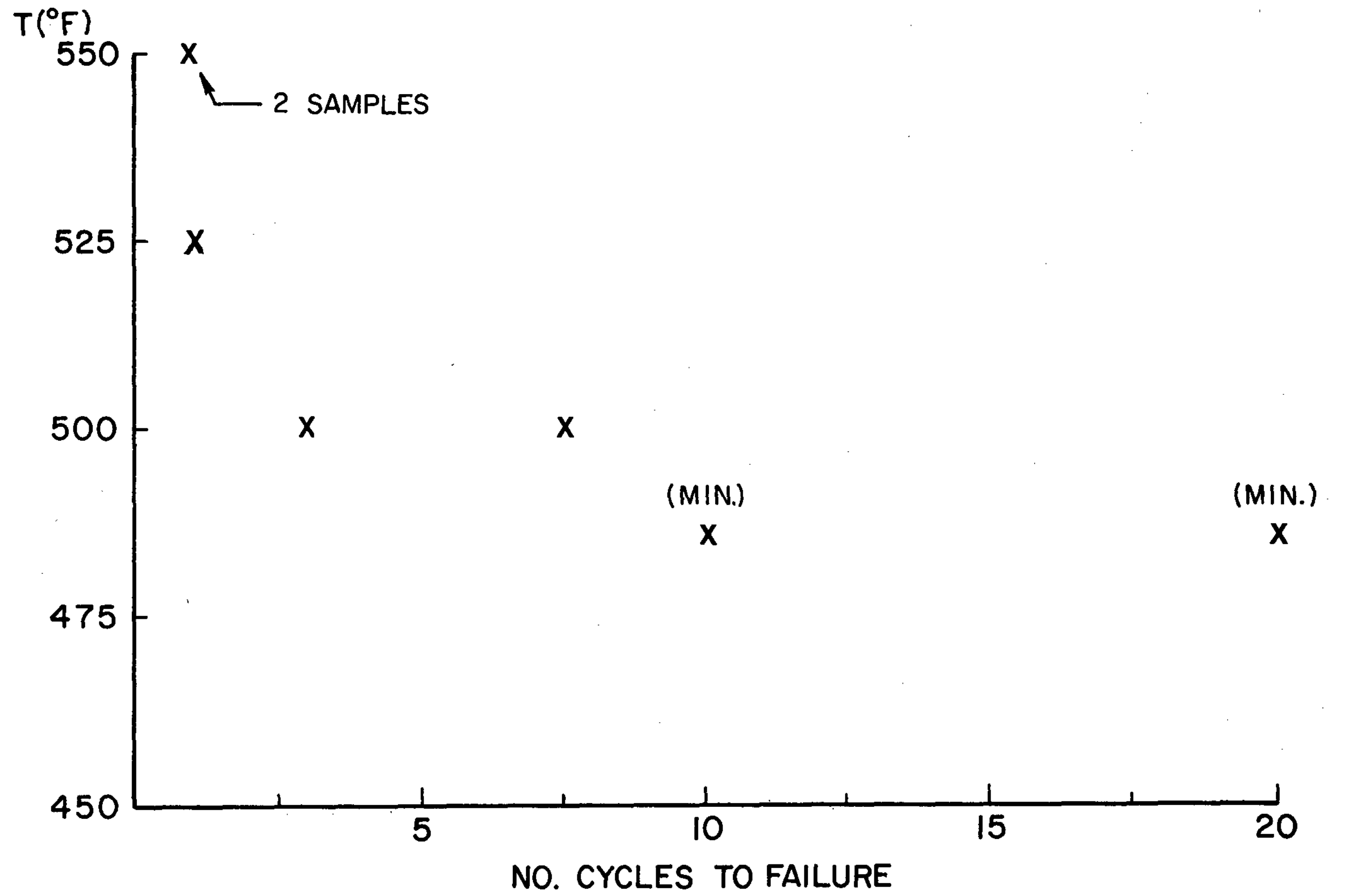


Figure 16. Evaluation of a Continuous-Fillet Specimen of 3M Company Polyester Sealant EC 2278. Temperatures given are vapor temperatures. Simulated liquid temperature was 250°F for all cases.

developed, heat distribution was made more uniform, heater spacing was increased, and procedures for reducing the effects of residual thermal distortions were developed. Extended evaluations can now be made without tearing of the material prematurely. Recently, the appearance of the sealant material after failure implies that thermal degradation is playing a major role in failure of the seals.

In a few recent instances, a seal has shown a leak at elevated temperatures, and the leak has "disappeared" when rechecked at room temperature. In one case a differential pressure across the sealant of several psi failed to produce bubbles when the checking procedures described in Section III was followed.

A paper resulting from the Elastomer Evaluation Program entitled, "Dynamic Laboratory Evaluation of Integral Fuel-Tank Sealants," by Dr. William R. Mallory and Elmer V. Harbert, Jr., of SRL and William F. Anspach of AFML will be presented at the SAMPE Conference in Fort Kiamesha, New York, 17-19 October 1978. The paper describes the evaluation apparatus and evaluation results to date.

SECTION V

CONCLUSIONS

Elastomeric materials used in sealing integral fuel tanks in high-performance aircraft are exposed to complex environmental conditions such as mechanical loading in the presence of fuel and high temperatures. The Air Force has a critical need for rapid, economical, and realistic evaluation of these sealant materials. To provide an economical facility for dynamically evaluating these sealants, a unique system has been developed which subjects the sealant material in the laboratory to mechanical forces, pressures, temperatures, and fuel-exposure conditions closely simulating those experienced in aircraft integral fuel tanks during flight. The system can simulate a complete flight profile including fuel loading, take-off, cruise and high-speed flight, landing, and shutdown. The system is capable of repeating these simulated flight conditions to a high degree of accuracy. The equipment allows automatic evaluation of elastomeric sealants using a variety of joint configurations.

This bench-scale dynamic evaluation capability allows accurate prediction of the performance of sealant materials in use. Preliminary screening of sealant materials for new aircraft can be accomplished in this apparatus and, therefore, the apparatus permits a reliable selection of the optimum sealant and/or sealing system for the aircraft. The capability provided by this apparatus also can contribute directly to reduction in operation and maintenance cost since field-use conditions can be simulated when solving sealant problems on operational aircraft. Therefore, the need for costly and time-consuming flight tests is eliminated or reduced. Another, and perhaps the most important, feature of this dynamic evaluation apparatus is that it can serve as a research tool for studying sealant materials and their performance characteristics. For example, it can be used to establish the critical parameters for long service life (e.g., temperature range, adhesion, elongation, and tear resistance) for each important class of sealant materials. It is also useful for the evaluation and comparison of new experimental sealant materials and for providing data to be used in life-prediction techniques based upon accelerated testing.

Continuous-fillet sealant specimens utilizing EC 2288 polyester sealant made by the 3M Company has been partially evaluated using the first evaluator described in Section II. Effects of thermal distortions of the specimen disc discovered early in the program have been minimized, and a satisfactory detector for sealant failure has been discovered.

A second evaluation machine similar to the first is presently under construction. The new machine incorporates modifications made to the first machine during development as well as some additional improvements.

Test specimens for evaluation of continuous-fillet sealants have been constructed. Specimens for corner and channel configurations have been designed. All test specimens employ a special disc with a recessed center section to minimize the effects of thermal distortion.

A paper describing the equipment has been prepared for presentation at the 1978 SAMPE Conference. Evaluation results will be presented as part of the paper.

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